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CONSTRUCTION OF A SENSOR FOR CONTINUOUSLY RECORDING THE CHANGE IN HEIGHT OF PLANTS IN THE FIELD

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CONSTRUCTION OF A SENSOR FOR CONTINUOUSLY RECORDING THE CHANGE IN HEIGHT OF PLANTS IN THE FIELD

Wendell C. Johnson and Ronald G. Davis[2]

Diurnal fluctuations in growth rate of irrigated sorghum and wheat have been reported earlier.[3,4] To obtain the data for these publications, a height sensor was used in conjunction with a strip chart recorder. This publication describes the construction of this height-sensing instrument.

Figure 1 shows the basic parts of the height sensor. Its one moving part is an integral Plexiglas disk and axle that turns on a horizontal axis. The disk and axle are housed in a Plexiglas box attached to one leg of a supporting tripod by a laboratory support flange, aluminum support rod, and a fixed clamp holder.

The sensor is connected to the plant with a fine copper wire, one end of which is attached to the disk near the axle and is wound one turn around the axle. A weight cord also is attached to and wound around the axle but in the opposite direction. The cord would cause the disk to rotate if the disk was not restrained by the copper wire attached to the plant.

The output voltage signal from the sensor is taken from a resistance slidewire that lies along a portion of the circumference of the plastic disk. A voltage regulator places a known constant voltage across the slidewire, and as the plant grows, the disk is allowed to turn. As the distance between the upper end of the resistance slidewire and the contact point increases, an increasing voltage output signal is produced.

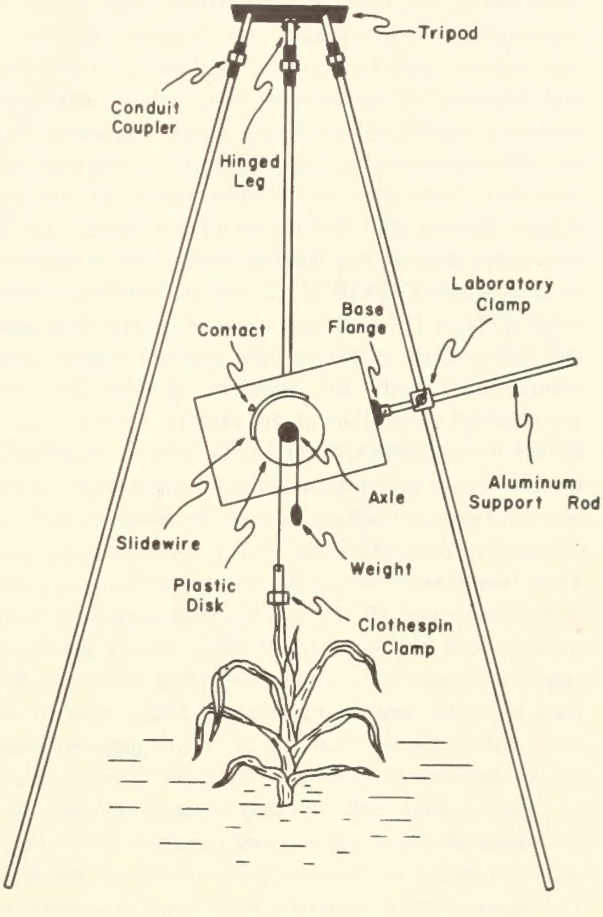

Figure 1.—A height sensor for obtaining a continuous record of plant growth.

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[2] Research soil scientist and agricultural research technician, respectively, USDA, Southwestern Great Plains Research Center, Bushland, Tex.

[3] Johnson, Wendell C. Diurnal variation in growth rate of grain sorghum. Agron. J. 59: 41-44. 1967.

[4] Johnson, Wendell C. Diurnal variation in growth rate of irrigated wheat. Agron. J. 61: 539-542. 1969.

APPARATUS

Tripod Support

The top of the tripod support is a 1/8- by 6- by 6-inch metal plate to which stub legs approximately 6 inches long have been brazed. One of the legs is hinged to make the tripod easier to manage in the field. Sections of half-inch electrical conduit of suitable length for the crop being studied are connected to the stub legs with standard threaded conduit couplings.

To reduce the temperature effects, invar steel tubing[5] (which has an extremely low coefficient of linear expansion) was used for the tripod legs during the measurement of the growth rate of wheat. However, the use of invar was discontinued because of its high cost and because of indications that temperature effects probably would not limit the overall accuracy of the growth measurements. As an example of the error to be expected from the temperature effect on the steel tripod, assume that the height of the sensor is 5 feet above the ground, the thermal coefficient of expansion of steel is about $12 \times 10^{-6}/^\circ$ C., and the daily temperature range is about 15° C. In this reasonably typical situation, the temperature effect on the support tripod is only about 0.01 inch of apparent growth per day's temperature range. Part of this effect is compensated for by the greater temperature coefficients of expansion of the downward pointing aluminum support rod, Plexiglas box, and copper wire connecting the sensor to the plant. Change in circumference of the Plexiglas axle causes some temperature error, but this amounts to only about 0.0040 inch per 15° C. and is compensated for by the simultaneous change in length of a 15-inch segment, or about the length of copper connecting wire used. Field tests with the sensors attached to 2-foot pine or invar steel stakes showed that the error in measured growth due to the temperature range of a clear summer day did not exceed 0.01 inch. We also determined that rain or the condensation of atmospheric moisture as dew had no apparent effect on the signal recorded from the sensor. The absence of a moisture effect on the apparatus is important in observing the effect of dew or the beginning of a rain on plant growth.

Because our studies have been limited to rapid growth situations involving young leaves where the measured growth is about 1 inch or more per day, errors of the magnitude caused by temperature effects on the tripod support have not been considered important. However, for measuring during expreme termerature changes, or if the plant growth per day is small, it would probably be advisable to use invar legs.

Field installation of the tripod involves making three inclined holes 10 to 12 inches deep with either an auger or soil probe slightly larger in diameter than the tripod legs. The legs are then placed into the holes and are forced into the soil an additional 10 to 12 inches when soil moisture conditions permit.

The sensor and its support should be in stable equilibrium. Greatest stability is achieved when the center of gravity of the sensor box is in the lowest possible position, which is when the sensor is located over the center of the triangle formed by the base of the tripod. Also for stability, the end of the support rod opposite the sensor box should point into the prevailing wind so that the orientation of sensor and rod is similar to that of a wind vane.

Sensor

The outside dimensions of the assembled Plexiglas box are 3 3/8 by 8 3/16 by 9 3/4 inches (fig. 2). One of the sides is hinged at the top to allow access to the electrical components. The front, back, and top are cut from 3/16-inch stock and the ends and shelf from 3/8-inch stock. The bonding material used was Rez-n-bond.[6]

The sensor shown in figure 3 has a disk diameter ot 5 inches, a slidewire 6 1/8 inches long, and an axle diameter of 1.46 inches. Used with a 0- to 9-mv. recorder, with a calibration constant of 0.20 inch of growth per mv., the sensor has a range of 1.8 inches without resetting. The range can be increased, with a reduction in sensitivity, simply by increasing the diameter of the axle. Sensors with a range of 1.6 to 1.8 inches have been used satisfactorily to measure the growth of wheat, soybeans, and sugarbeets. Sensors used for measuring corn and grain sorghum growth have had a range of 3.2 to 3.6 inches.

The shaft for the disk and axle is 3/32-inch piano wire and turns in ball bearings mounted on the shelf.[7]

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[5] Invar tubing available from J. Bishop and Co., Malvern, Pa.

[6] Manufactured by Schwartz Chemical Co., Long Island City, N. Y.

[7] The shaft bearings, bearing supports, and retaining collars were originally intended for building slot racers and are available at hobby shops.

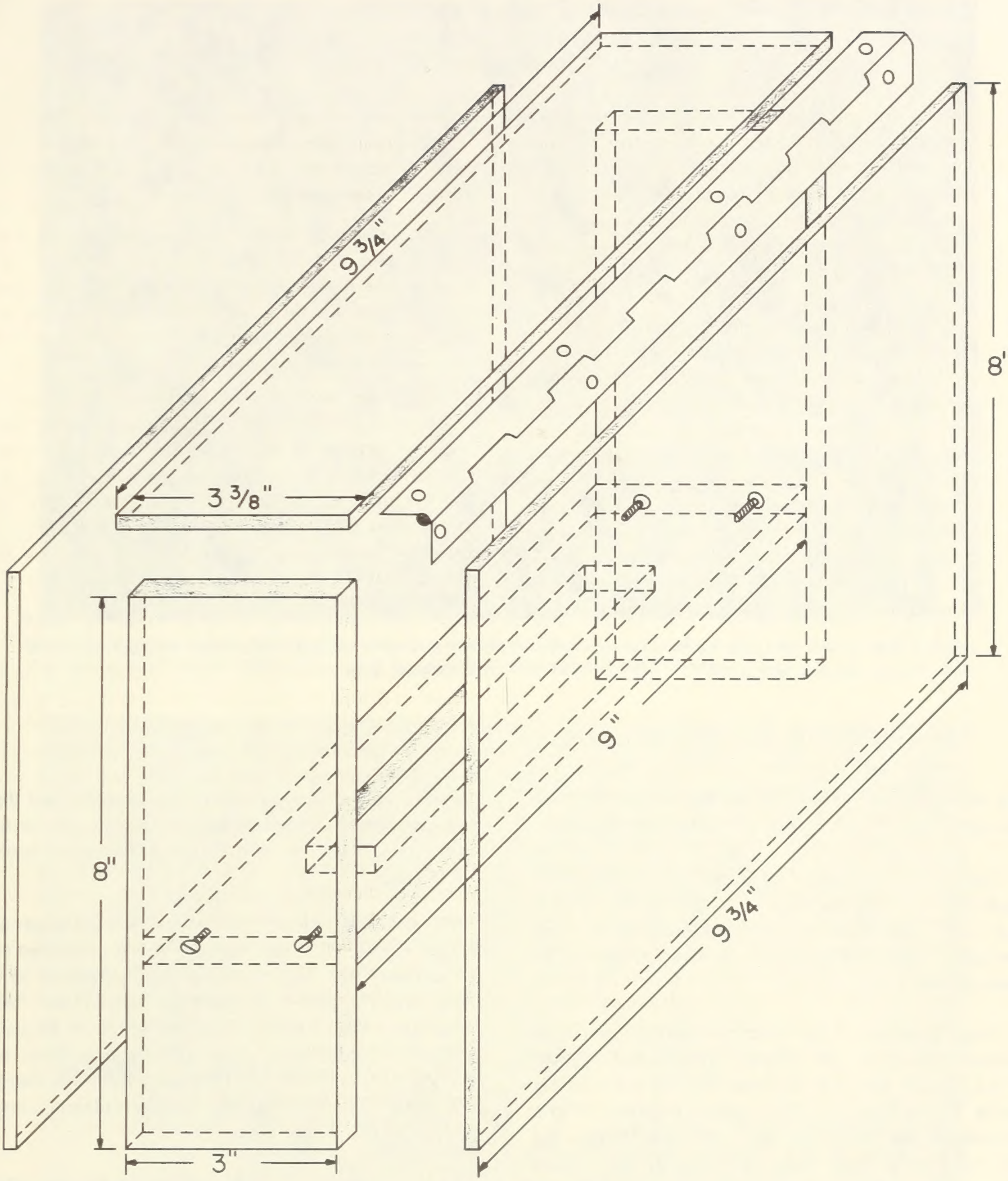

Figure 2.—Height sensor housing assembly and dimensions.

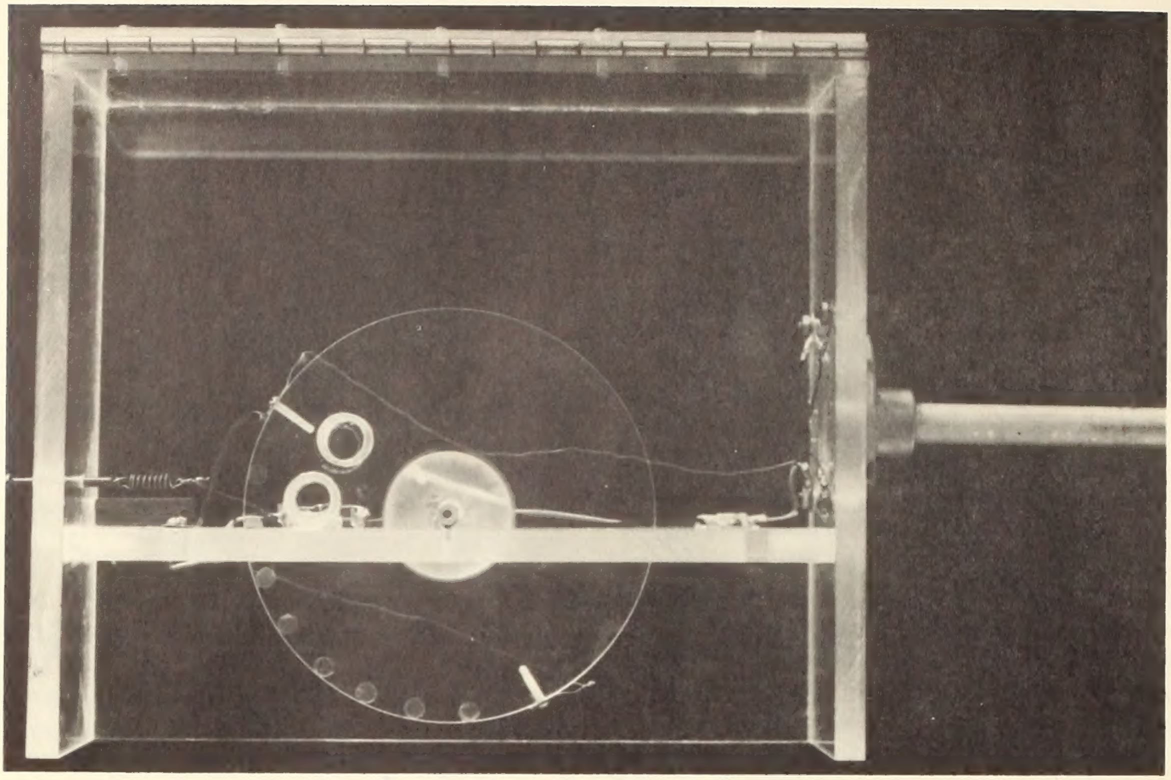

Figure 3.—Overall view of height sensor showing slidewire contact at one end of the slidewire as one of the stops strikes the shelf. The phonopickup wire connections to each end of the slidewire are also shown.

The slidewire disk extends above and below the shelf through a 1- by 6 1/2-inch slot cut in the shelf (fig. 4).

The contact arm, mounted at one end of the slot, is made from a double thickness of 0.005-inch shim brass 1 inch wide. Actual contact with the slidewire is made through a piece of 24-gage platinum wire soldered to the brass contact arm.

Fine adjustment of the contact pressure is made using a screw threaded through the end of the box and attached to the contact arm by a light bronze spring and a fishing tackle swivel (fig. 5). The contact pressure on the slidewire should be kept as light as possible to allow the disk to turn with as little counterweight as possible without having the contact stick cause a "stairstepped" record. About 30 grams is the minimum amount of weight that can be used.

To allow the sensor to operate properly with a minimum contact pressure, the slidewire and contact must be kept clean. The slidewire should be rubbed with a pencil eraser, then with a clean handkerchief, and the platinum contact should be burnished with a piece of paper. The slidewire and contact should be cleaned every 2 or 3 days.

The sensor and the plant are connected by a length of 30-gage copper wire, one end of which is connected to the slidewire disk and the other end is fastened to a clamp which in turn is attached to the plant leaf. The clamp is an ordinary spring-type clothespin with the jaws modified by cementing pieces of plastic to them to produce a gripping surface of 3/4 by 1 inch. The clamp jaws are faced with a sponge rubber-moleskin cloth material or with sponge rubber.[8]

Stops made of 3/4-inch lengths of 5/8-inch OD polystyrene tubing[9] cemented to the slidewire disk with

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[8] Dr. Scholl's Molefoam, which has its own adhesive (softens somewhat in wet weather), or pieces of sponge rubber innersole fastened with contact cement.

[9] Obtained from Burstein-Applebee Co., Kansas City, Mo.

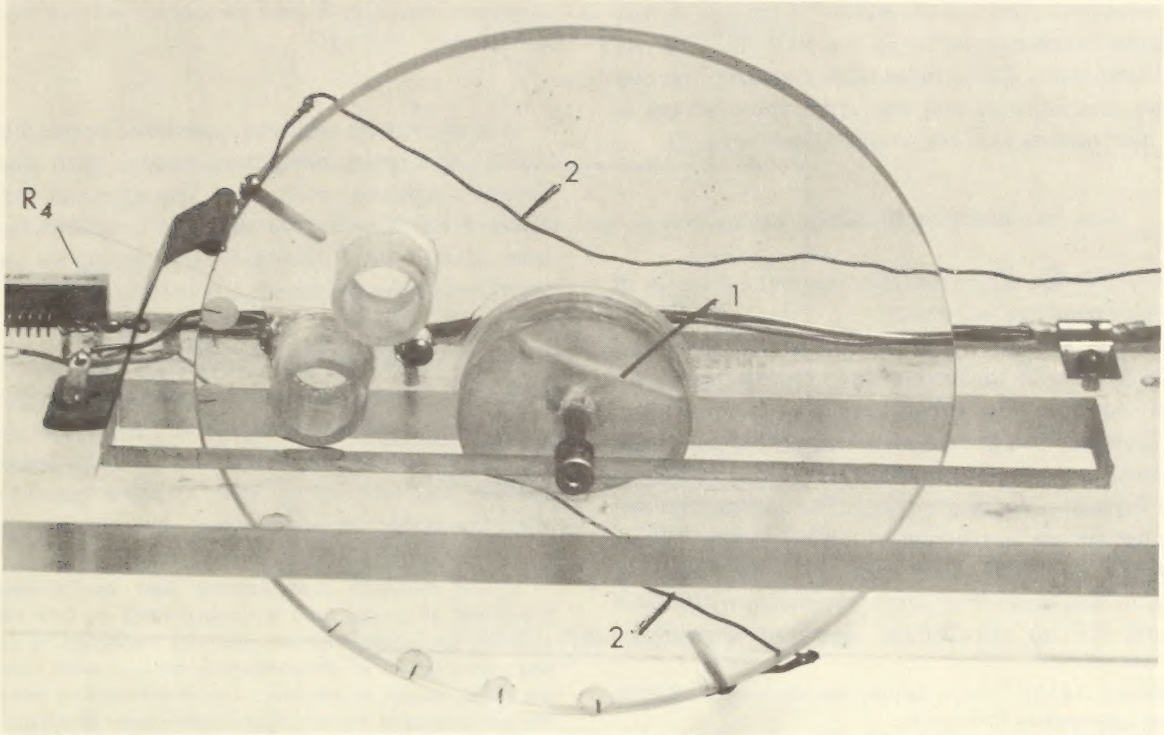

Figure 4.—Position of disk in slot in plastic shelf. Visible at the back of the shelf is the zero-adjust resistor, R_4, which is adjustable through a hole in the end of the case. Note also (1) the chordal hole through the axle, visible from the end of the axle used for attaching the weight cord, and (2) the phonowire connections to the slidewire.

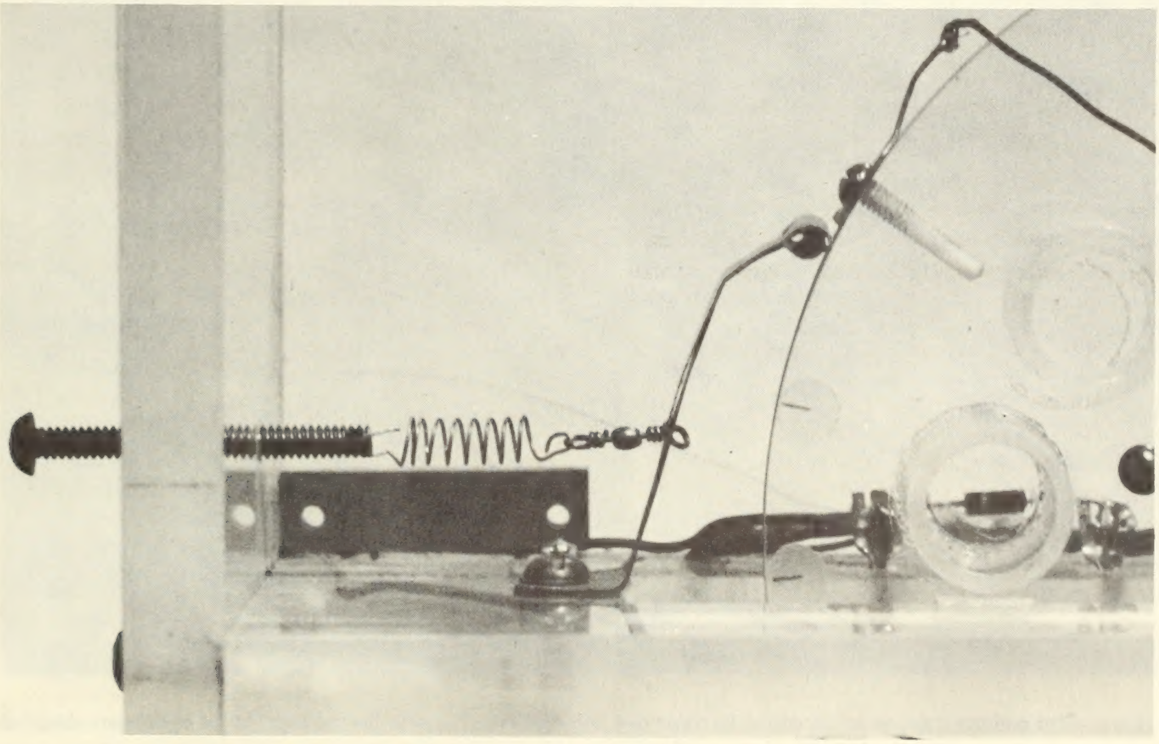

Figure 5.—Slidewire contact whose pressure is adjustable from outside the plastic case.

Rez-n-bond limit the angle of rotation of the disk so that the fragile connecting wires to the slidewire will not break if the clamp comes loose from the plant. The two stops are positioned so that they strike the shelf top as the contact reaches each end of the slidewire (fig. 6).

Electrical Circuit

Figure 7 shows schematic diagrams and a parts list of the voltage regulator and sensor.

It is convenient to operate three sensors from each voltage regulator. The voltage regulator is built into a small Minibox. The Minibox is wrapped in sheet plastic to protect it from the weather and is mounted on a tripod leg with a laboratory clamp. The voltage regulator is connected to a laboratory power supply[10] with lightweight extension cord wire. The power supply, housed in the recorder shelter, furnishes a well-filtered 10 volts d.c. to the voltage regulator. Lightweight extension cord also is used to connect voltage regulator and sensors.

A single voltage regulator (resistance values shown in figure 7) is used with three sensors, each having a slidewire resistance of 5 ohms. The apparatus shown in figure 7 was designed for use with a recorder having a span of 0-9 mv.[11] Shielded cable should be used for signal leads from the sensors to the recorder.

The voltage regulator provides a constant voltage across the sensor slidewires independent of fluctuations in temperature and line voltage. A 5.6-v. Zener diode is used in the voltage regulator. The circuit is designed to operate the Zener diode with a reverse current of 50 ma., the condition under which its operation is least

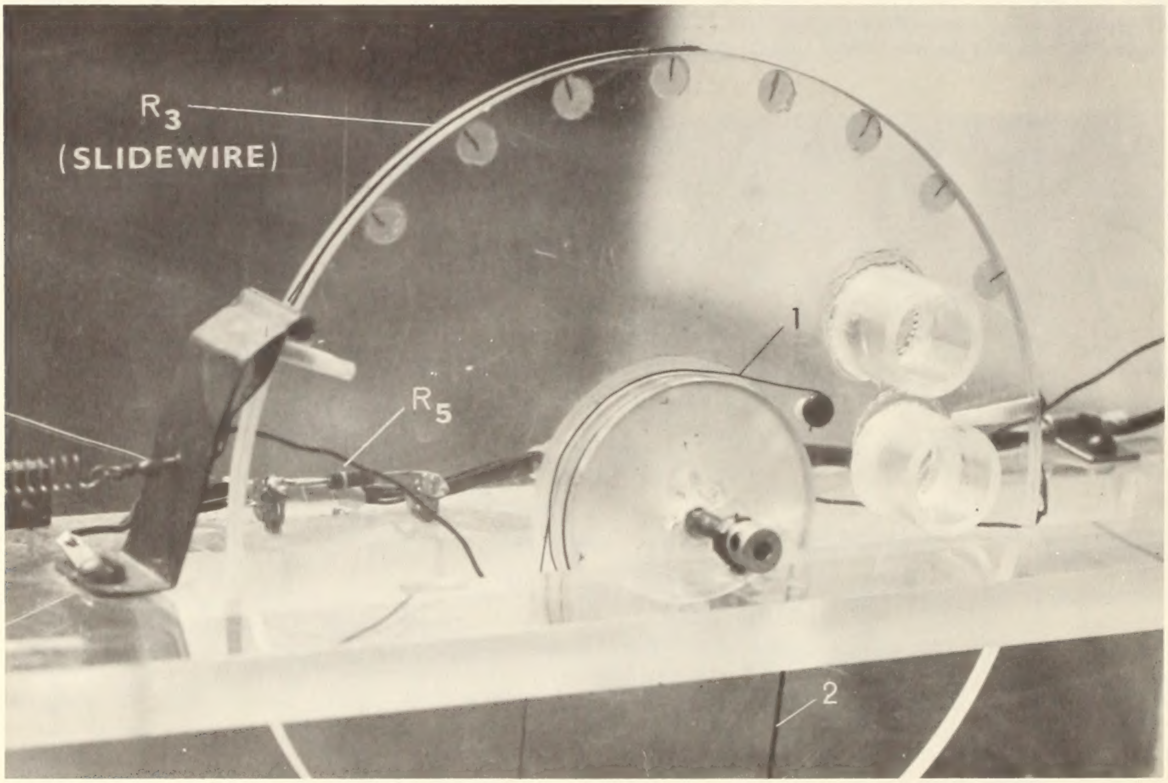

Figure 6.—The contact is shown at the end of its travel over the slidewire, R_3, with the stop against the right-hand side of the shelf. Resistor R_5 is visible at the back of the shelf together with its "flea clip" mountings. The clamp wire (1) and weight cord (2) are in place wound in opposite directions around the axle. The millivolt dial-marks can be seen along the rim of the disk.

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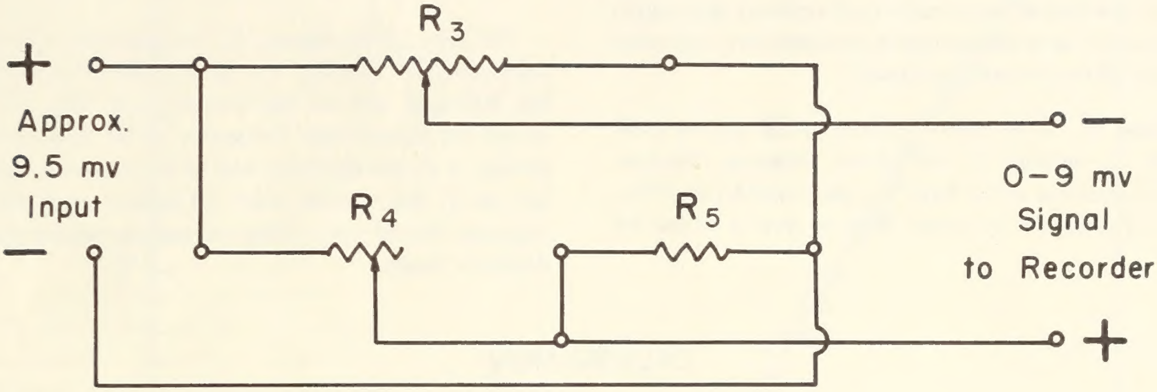
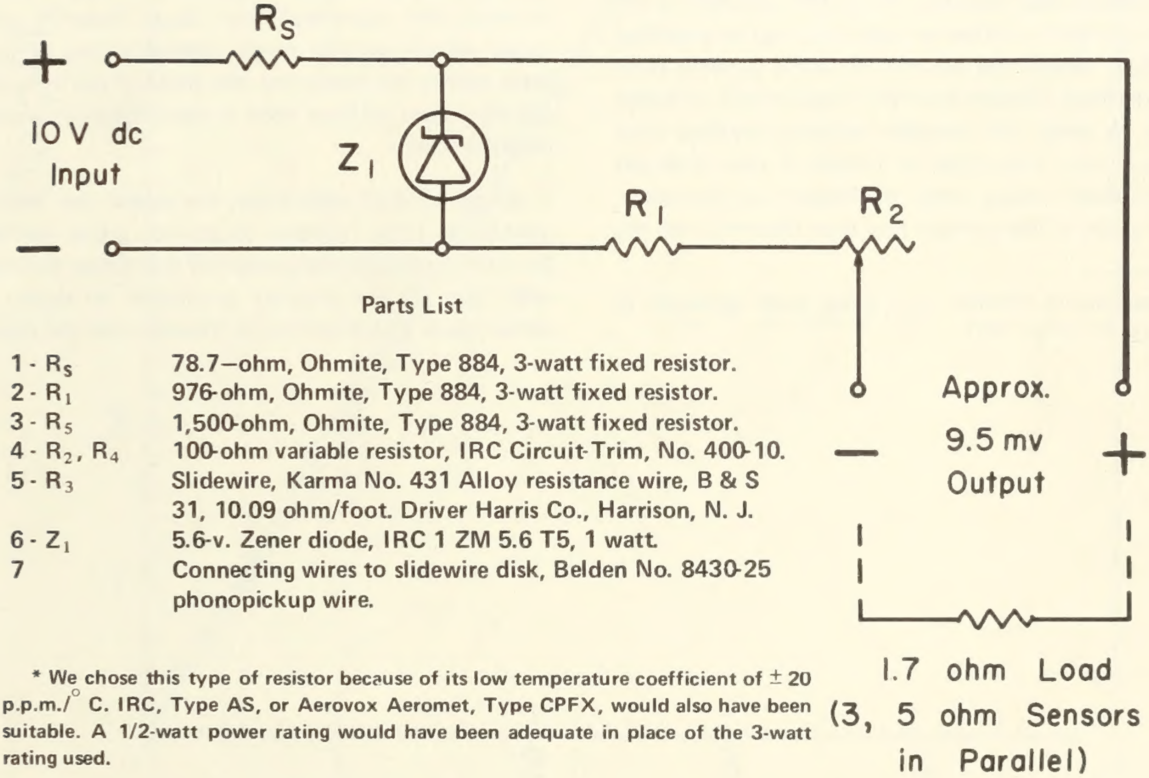
[10] Electro D-6127 T Power Supply manufactured by Electro Products Laboratories, Chicago, Ill.

[11] The recording potentiometer used was a Honeywell Electronik 15 model with a nominal range of 0-10 mv. This recorder is equipped with an accessory event-marking pen that was connected to an anemometer to obtain a wind trace along the upper margin of the chart. Use of the marking pen limited the useful range of the recording potentiometer to 0-9 mv.

(A) Growth Sensor



(B) Voltage Regulator



Parts List

1 - R_S	78.7—ohm, Ohmite, Type 884, 3-watt fixed resistor.
2 - R_1	976-ohm, Ohmite, Type 884, 3-watt fixed resistor.
3 - R_5	1,500-ohm, Ohmite, Type 884, 3-watt fixed resistor.
4 - R_2, R_4	100-ohm variable resistor, IRC Circuit-Trim, No. 400-10.
5 - R_3	Slidewire, Karma No. 431 Alloy resistance wire, B & S 31, 10.09 ohm/foot. Driver Harris Co., Harrison, N. J.
6 - Z_1	5.6-v. Zener diode, IRC 1 ZM 5.6 T5, 1 watt.
7	Connecting wires to slidewire disk, Belden No. 8430-25 phonopickup wire.

* We chose this type of resistor because of its low temperature coefficient of ± 20 p.p.m./° C. IRC, Type AS, or Aerovox Aeromet, Type CPFX, would also have been suitable. A 1/2-watt power rating would have been adequate in place of the 3-watt rating used.

Figure 7.—Schematic diagrams and parts list of (A) growth sensor shown in figure 3; and (B) voltage regulator.

affected by temperature. Design considerations and temperature effects are discussed in the Zener Diode Handbook, pp. 24-27.[12] To further reduce temperature effects, low-temperature coefficient resistors are used in the regulator, and low-temperature coefficient resistance wire is used for the sensor slidewire.

Because of its flexibility, phonopickup wire is used for the connections to the sensor slidewire. Because these connecting wires have an appreciable resistance, there is a voltage drop across them as well as across the slidewire. The span adjust resistor, R^2, in the voltage regulator is needed to make the voltage drop across the slidewires exactly equal to the span of the recorder.

The zero adjust resistor, R_4, in each sensor gives the positive signal terminal the same electrical potential as the left-hand side of the slidewire, R_3 (fig. 7). This causes the signal from the sensor to be zero when the contact is at the left-hand end of the slidewire, enabling full use of the recorder span. All sensors using the same regulator should have slidewires and connecting wires of the same length.

CALIBRATION

The sensor should be calibrated in the laboratory before being used in the field. In our calibration setup, the support rod was clamped rigidly in a horizontal position to a vertical rod with a laboratory clamp. The clamp wire was attached to the support arm of a small photographic enlarger that had a vernier arrangement for precise raising and lowering. A pointer attached to the support arm and a millimeter scale mounted on a vertical mirror just behind the pointer (to avoid parallax error during reading) allowed accurate measurement of height changes. A series of recorder millivolt readings were made at 1-mm. increments of height. A plot of height versus millivolt output tested the linearity of the sensor, and the slope of the straight line thus obtained was the calibration constant of the sensor in terms of height per millivolt output (fig. 8). The linearity of the sensor depends on the accuracy of the lathe work in turning and centering the disk and axle, as well as on the uniformity in diameter and composition of the slidewire.

It is not difficult to construct a sensor of excellent linearity and reproducibility. Good linearity of the sensor output permits direct determinations of growth rates simply by measuring the slope of portions of the recorder trace without need to consider position on the recorder scale.

At the time of calibration, the sensor disk should be marked at 1-mv. intervals to provide a dial reading. In the field, a routine comparison of the sensor dial reading with that of the recorder is valuable to detect poor connections in the wiring or trouble with the recorder.

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[12] International Rectifier Corp., Zener diode handbook. El Segundo, Calif. 74 pp. 1961.

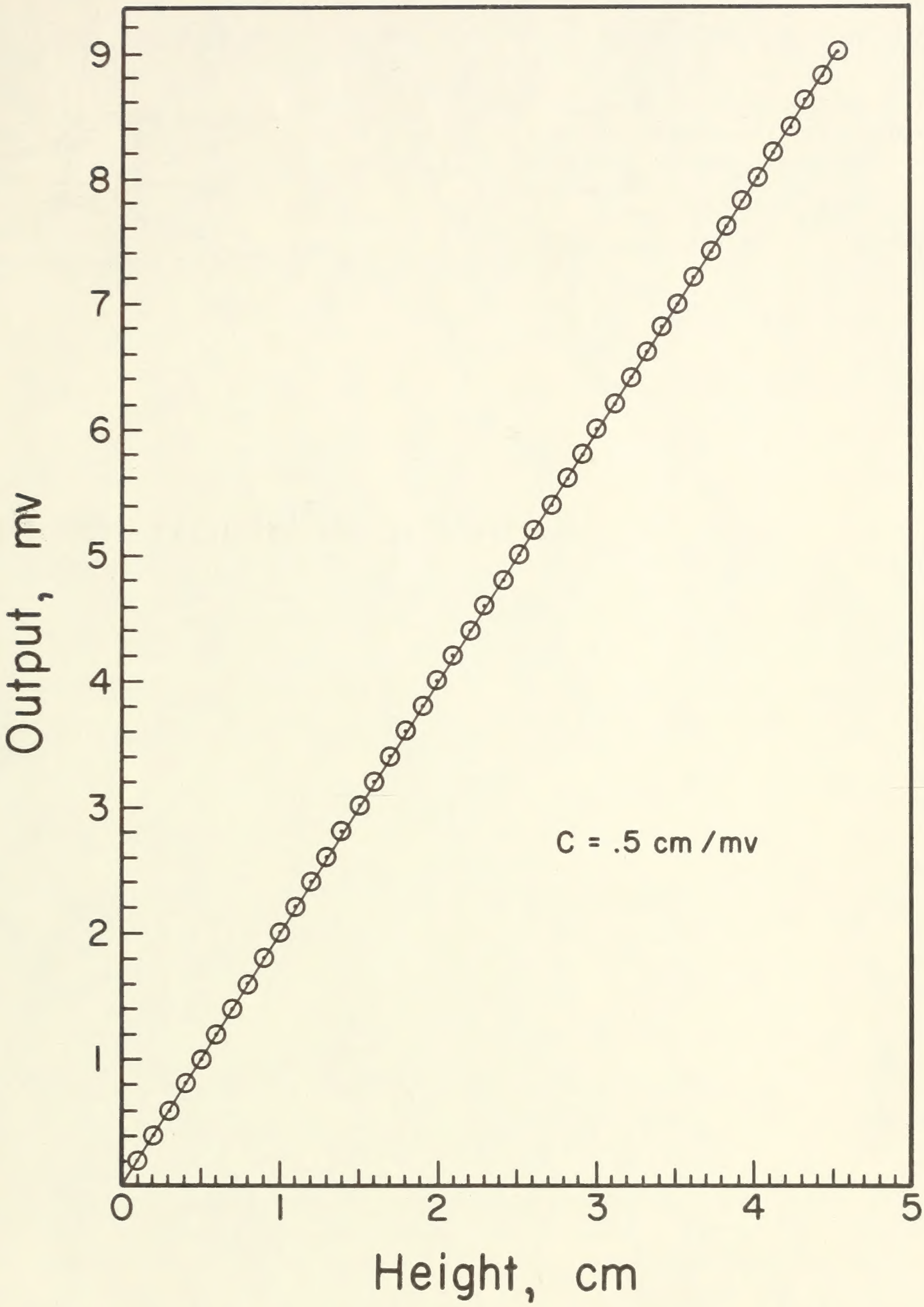

Figure 8.—Calibration curve of height sensor shown in figure 3.

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